STRUCTURAL TIME DOMAIN IDENTIFICATION (STDI) TOOLBOX FOR USE WITH MATLAB

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ABSTRACT

The Structural Time Domain Identification (STDI) toolbox for use with MATLAB™ is developed at Aalborg University, Denmark, based on the system identification research performed during recent years. By now, a reliable set of functions offers a wide spectrum of services for all the important steps of multivariate time domain system identification of time-variant as well as time-invariant civil engineering structures from ambient testing data. A graphical user interface (GUI) is also developed to make the toolbox more user friendly.

1. INTRODUCTION

The MATLAB™ program (Mathworks Inc.) is a High-Performance Numeric Computations and Visualization Software. MATLAB integrates numerical analysis, matrix computation, signal processing, and graphics in an easy-to-use environment where problems and solutions are expressed just as they are written mathematically - without traditional programming. The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects, which together represent the state of the art in software for matrix computation. MATLAB is an interactive system whose basic data element is a matrix that does not require dimensioning.

MATLAB has evolved over a period of years with input from many users. In university environments, it has become the standard instructional tool for introductory courses in applied linear algebra, as well as advanced courses in other areas. In industrial settings, MATLAB is used for research and to solve practical engineering and mathematical problems. Typical uses include general purpose numerical computation, algorithm prototyping, and special purpose problem solving with matrix formulations that arise in disciplines such as automatic control theory, statistics, digital signal processing (time-series analysis), etc.

MATLAB also features a family of application-specific solutions that are called toolboxes. Very important to most users of MATLAB, toolboxes are comprehensive collections of MATLAB functions (m-files) that extend the MATLAB environment in order to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems design, dynamic systems simulation, systems identification, neural networks, and others. This allows one to create own applications without writing a single line of C, Fortran or other low-level code.

For system identification several toolboxes exist. System identification is a way to find a mathematical model for a physical system (like an electric motor, or even a financial market) based only on a record of the inputs and outputs of that system.

The System Identification toolbox, Ljung [1] features a flexible Graphical User Interface (GUI) as well as identification functions that implement both parametric and nonparametric identification techniques. Written by Dr. Lennart Ljung, [2] a recognized leader in the field of system identification, the toolbox contains carefully implemented algorithms to ensure efficiency and reliable numerical results. All the data sets and models created with the GUI are represented by icons. An entire session of data and models, along with relevant diaries, can be saved for reloading at a later time.

The Frequency Domain System Identification Toolbox, Kollár [3], Kollár et al. [4], contains tools for accurate modelling of linear systems with or without delay. The models are transfer functions in the s-domain or in the z-domain. The procedures include excitation signal design, data preprocessing, parameter estimation, graphical presentation of results, and model validation (tests, uncertainty bounds, modelling errors). The two mentioned toolboxes are official, sold by Mathworks Inc, while the following system identification toolboxes mentione are unofficial.

The SSID toolbox, Mckelvey [5] provides identification routines for identification of multivariable state-space models from input/output data. The main feature of the toolbox is that the models do not use the standard identifyable state-space parameterizations but a full parametrization of all state-space matrices. In order to use the SSID-toolbox the System Identification Toolbox, Ljung [1], is required.

The SENSTOOLS toolbox, Knudsen [6], is a toolbox for direct estimation of physical/continuous-time parameters in linear and nonlinear systems from input-output measurements. The m-files are functions for input signal design, parameter estimation and model validation.

The NNSYSID toolbox [7] is a neural network based nonlinear system identification toolbox which contains a large number of functions for training and evaluation of multilayer perceptron type neural networks. The main focus is on the use of neural networks as a generic model structure for the identification of nonlinear systems.

However, in order to use the above-mentioned toolboxes for identification of structural systems one is missing functions for the estimation of the modal parameteres and mode shapes. Recently, some MATLAB toolboxes made for solving structural engineering identification problems have been presented.

The purpose of the Structural Dynamics Toolbox, Balmés [8] is to provides low cost, modular, and versatile access to methods in experimental and analytical structural dynamic modelling. The toolbox includes functions for experimental modal analysis, Finite Element analysis and Finite Element design and update. A GUI provides a layer of predefined operations for Frequency Response Function visualization and analysis, identification and 3-D deformation animation.
The *X-modal* modal analysis software package, Phillips et al. [9], was delveloped as a collaboration between the University in Cincinnati and the industry. The software is based on The Unified Matrix Polynomia Approach (UMPA), Fladung et al. [10]. The unified approach to modal parameter estimation within the context of *X-modal* invloves not only the formulation of the algorithms, but also the presentation of their controlling parameters. This software package was programmed using the MATLAB language, The 'C' language and the X windows system.
However, a MATLAB toolbox consisting of only m-files for structural system identification based on time domain techiques is to the authors' knowledge not available. Therefore the members of the Structural Time Domain Edentification group at Aalborg University, Denmark, decided to develop the STDI toolbox, Andersen et al. [11] based on the system identification research performed during recent years. By now, a reliable set of functions offers a wide spectrum of services for all the important steps of multivariate time domain system identification of time-invariant as well as time-variant civil engineering structures from ambient testing data. These functions have mainly been developed as a part of the research presented in Andersen [12], Kirkegaard et al. [13] and Kirkegaard et al. [14]
Since the STDI toolbox is mainly developed for identification of civil engineering structures a large part of the functions is implemented from a civil engineering point of view, i.e. nearly all the implemented parameter estimation algorithms only use output data (ambient testing). Some of the alorithms also work on input - output data. The functions are usable either as stand-alone functions or through a menu driven GUI, for frequent and infrequent users, respectively. I.e. the GUI is a complement rather than an alternative: all functions can either be run in command mode or in GUI mode, and one can freely mix the two modes. The goal is, however, that the typical user should be able to run any application entirely in GUI mode if he or she prefers that. The whole toolbox is entirely written as MATLAB m-files, so it can be executed from any platform that is supported by MATLAB. Windows-MATLAB is required in order to use the developed GUI . The toolbox is not dependent on other MATLAB toolboxes. The aim of the present paper is to present an overview of the STDI toolbox.

2. AN OVERVIEW OF STDI FUNCTIONS

This section describes of the type of functions in the Structural Time Domain Identification Toolbox by listing function-types grouped by subject area. The overall objective of developing the STDI toolbox has been to make a set of functions for system identification of civil enginering. However, the aim has also been to make functions to facilitate the system identification process.
The first step in the identification process is to "book-keep" the identification step and acquire data. Figure 1 shows that STDI offers functions for "book-keeping", structural geometry preprocessing (nessary for showing mode shapes) and algorithms for making the interface to data acquisition PC plug-in cards.

For preprocessing of the data the STDI toolbox contains a whole range of functions, see figure 2. The preprocessing makes the measured signals suitable for identification. Further, the preprocessing fucntions can be used to show and to estimate statistical charateristics of the measured data.
For identification the STDI toolbox includes algorithms for identification of time-invariant systems, see figure 3 as well as time-variant multivariate systems, see figures 3 and 4. Apart from the well-known system identification techniques also a subspace identification algorithm (N4SID), Van Overschee et al. [15] is implemented. The acronym N4SID stands for Numerical algorithm for Subspace State Space System Identification.
For assessing the "quality" of the identified models the STDI toolbox offers several functions, see figure 5 such as FPE and AIC criteria, plot of the poles and zeroes, plot of the match of the power spectrum obtained by a Fast Fourier Transformation and the spectrum obtained from the identified model. Also functions to make plots of the spectrum and autocorrelation of the residual time series are given, and functions to compare the model output with recorded output.
After model validation, or combined with model validation, one has to select a model. The STDI toolbox gives several functions for model selection, mainly stabilization diagrams, see figure 6.
When a model has been selected and the modal parameters have been estimated it is important to be able to qunatify the uncertainty of the estimated parameters. This is possible for some of the identification algorithms in the STDI toolbox, see figure 7.
After an appropriate model has been validated and selected the system identification results have to be exported. Here the STDI toolbox offers functions, see figure 8, for making data tables with modal parameters and plots of e.g. mode shapes and measured data etc.
Besides the functions directly used in the identification process, a lot of auxiliary functions are implemented, e.g. functions for : transformation between continuous models and discrete models, handling and evaluating state- space systems, Random Decrement estimation, matrix polynomia calculations etc.

Information Importing
Project book-keeping (load, save....)
Structural geometry preprocessing
Data acquisition (Interface to Data Translation plug-in AD-boards, load/save data files acquired in other data acquistion enviroments)

Figure 1 Information Importing.

Preprocessing

Scaling and trend removal

Removal of outliers

Show measured data

Show FFT/Autocoriance functions of measured data

Estimates of moments (mean, standard deviation ..)

Low, high or bandpass filtering

Decimation and resampling

Split up into identification and validation data sets

Figure 2 Preprocessing.

Parameter Estimation

2-stage LS estimation of an ARMAV model

Non-linear LS estimation of an ARMAV model

LS estimation of an ARV model

Eigensystem Realization Algorithm (ERA, ERA/DC)

Matrix block Hankel (MBH)

Subspace Methods (N4SID)

Figure 3 Parameter Estimation.

Recursive Parameter Estimation

Recursive non-linear LS estimation of an ARMAV model

Recursive pseudo-linear estimation of an ARMAV model

Recursive least-square estimation of an ARV model

Kalman filtering

Recursive instrumental variable method

Figure 4 Recursive Parameter Estimation.

Model Validation

FPE - Final Prediction Error Criterion

AIC - Akaike's Information Theoretic Criterion

Plot prediction errors

Plot measured and predicted response

Plot poles and zeros

Compares spectral densities of one or several istructures with response data

Figure 5 Model Validation .

Mode Selection Functions

Modal Assurance Criterion

Coordinated Modal Assurance Criterion

Modal Confidence Factor

Eigenfrequency stabilization diagram

Damping ratio stabilization diagram

Mode shape stabilization diagram

Modal stabilization diagram

Figure 6 Mode Selection Functions.

Assessing Model Uncertainty

Returns the covariance matrix of the estimated parameters

Compute the uncertainties of the modal parameters

Figure 7 Assessing Model Uncertainty.

Information Exporting

Tables with the estimated modal parmaters

Mode Shape Animation

Documentation (final report generating)

Figure 8 Information Exporting.

3. THE STDI GUI

All the functions presented in section 2 are stand-alone functions which can run in command-line mode. However, to make a more user-friendly toolbox, the STDI toolbox includes a Graphical User Interface (GUI). Recently, GUI toolboxes for system identification have been presented, see Ljung [14] and DeMoor et al. [16]. The latter is not written for use with MATLAB but Xmath. A GUI system identification toolbox belongs to a third generation software with the following benefits , see DeMoor et al. [16]

- *the user can tackle much more serious problems because he/she is releaved from programming subtleties (almost all of the interaction with the software happens via the mouse buttons)*

- *implies that book-keeping of tasks, models, data sets and interconnections, becomes relatively straightforward*

- *there is quite some user guidance by the GUI in terms of options and defaults that can be chosen*

- *GUIs are user friendly and one can learn to work with them in a couple of minutes, without the necessity of going through thick manuals*

To motivate the use of GUI for system identification a short history of user-interfaces is given in DeMoor et al . [16]. They split the user interfaces up in the three stages: Program User Interface, Command-line User Interface and Graphical User Interface. The Program User Interface is the era of lower level programming (Fortran, Pascal and C). Typically, the user-input consisted of programs with low level commands. The Command-line Interface allows the user to enter commands at the command-line. Contrary to the previous generation, the effect of the commands could immediately be inspected. The Graphical User Interface is made up of graphicl objects such as menus, buttons and plots. Using it is straightforward since it only requires manipulation of the three mouse buttons an at rare accasios, typing in the name of an object or data file. An overview of the discussion of user interfaces in DeMoor et al. [16] is given in table 1. The combination of powerful numerical algorithms for system identification and an GUI leads to intelligent and user-friendly identification software. The GUI in the STDI toolbox makes it possible to run the identification process entirely in GUI mode, or a combination of GUI modes and command-line mode. The GUI is developed to handle the different kinds of functions presented in figures 1 - 8. An example of an GUI is hsown in figure 9. This GUI can be used to animate mode shapes after a model has been established.

	Program User Iter-face	Command Line Interface	Graphical User Interface (GUI)
Input	programs	command-line	graphical
Output	text	variables	graphical
Element	low Level	high level	window
Start Level	very high	high	low
Flexibility	low	high	high
User gui-dance	none	limited	high
Syntax	complex	complex	simple
Expertise	high	high	limited
Computer	simple	simple	fast
Date	1960 1982	1982-1990	1990- ?

Table 1 Comparison of the distinct stages in the history of identification and control software, DeMoor et al. [16].

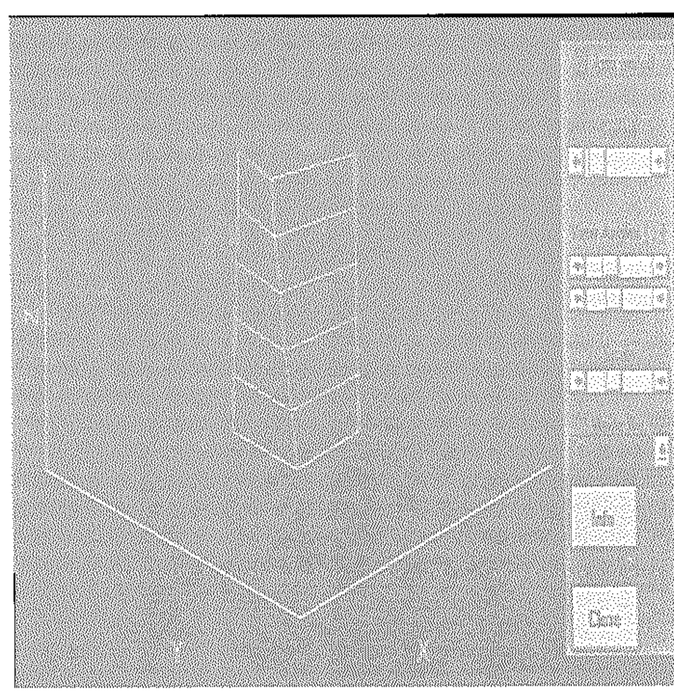

Figure 9 A Graphical User Interface for mode shape animation.

4. CONCLUSIONS

The present paper gives an overview of the GUI based Structural Time Domain Identification (STDI) toolbox for use with MATLAB™ is developed at Aalborg University, Denmark. The toolbox offers a reliable set of functions for all the important steps of multivariate time domain system identification of time-variant as well as time-invariant civil engineering structures. Further, the paper decribes how user-friendly identification software is obtained by combing numerical algorithms for identification with an GUI.

5. ACKNOWLEDGEMENTS

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